Simulation Study of Drift Chamber Performance

D. M. Asner, G. Tatishvili

Introduction

- There is considerable data on the tracking and dE/dx performance of drift chambers used in high energy physics experiments.
- The initial goal of our study is to understand the measured performance of drift chambers using the available software tools: Garfield, Magbolz, Heed.
- Our studies will focus on the BaBar and CLEO chambers (as the Canada SuperB effort includes both BaBar and CLEO members).
- This will (hopefully) allow us to understand the design decisions that were made by BaBar, CLEO etc.
- More importantly - if the simulations correctly model the observed performance then we have a set of powerful tools to optimize the design of the SuperB DCH.

Software Tools

Simulation studies have been performed using Garfield, Magboltz and Heed programs.

Garfield - **is a computer program for the detailed simulation of gaseous detectors.**

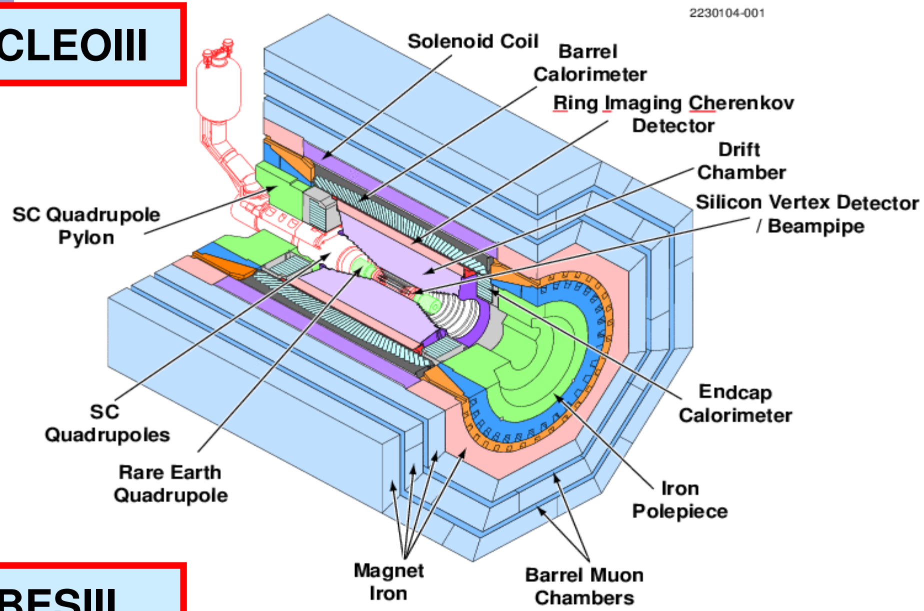
Magboltz - **provides the computation of electron transport properties in gas mixtures under the influence of electric and magnetic fields.**

Heed - **is a program that computes in detail the energy loss of fast charged particles in gases.**

We have used the newest Garfield 9 with Magboltz 7.

Principal Properties of e^+e^- Collider Detectors

CLEOIII



Drift Chamber:

- 93% of 4π
- $\Delta p/p$ = 0.32% @ p=0.5-1.0 GeV/c.

CsI Calorimeter (8000 crystals):

- 95% of 4π
- $\Delta E/E$ = 4% @ E=100 MeV.

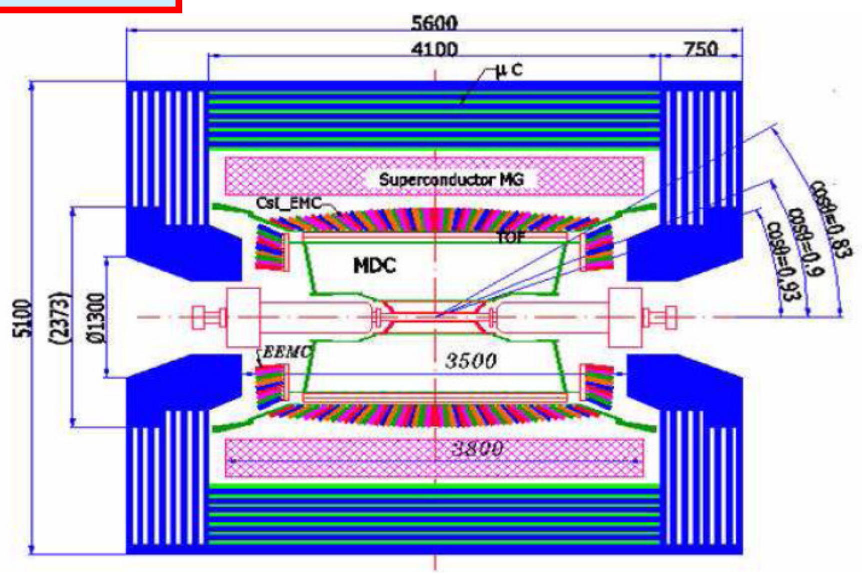
Muon Chambers:

- 85% of 4π
- Identify muons for p>1GeV/c

Particle Identification:

- RICH detector & dE/dx in DCH
- Combined ε (π or K) > 90%.

BESIII



MDC:

- 93% of 4π
- $\Delta p/p$ = 0.5% @ p=1.0 GeV/c.

CsI Calorimeter (6240 crystals):

- $\Delta E/E$ = 2.5% @ E=1 GeV.

Muon Counter:

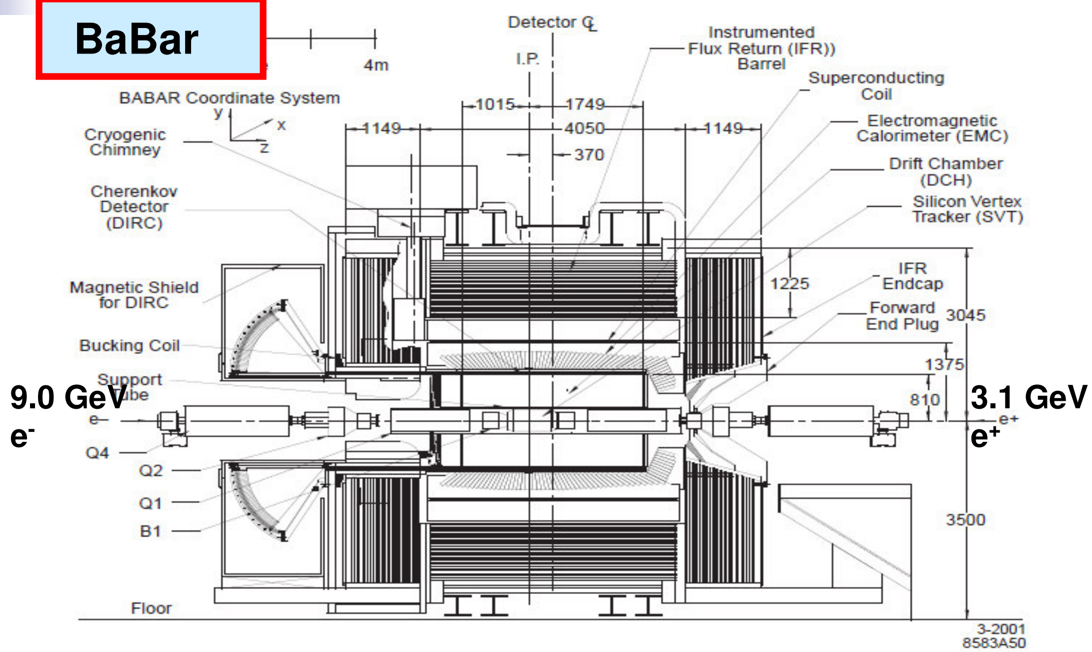
- 9 Layers

Particle Identification:

- TOF. σT=100-110 ps
- dE/dx in MDC

Principal Properties of e+e- Collider Detectors, cntd.

BaBar



DCH:

- $-0.92<\cos\theta<0.96$
- $\Delta p/p = 0.48\%$

CsI Calorimeter (6580 crystals):

- $\Delta E/E = 3.0\%$

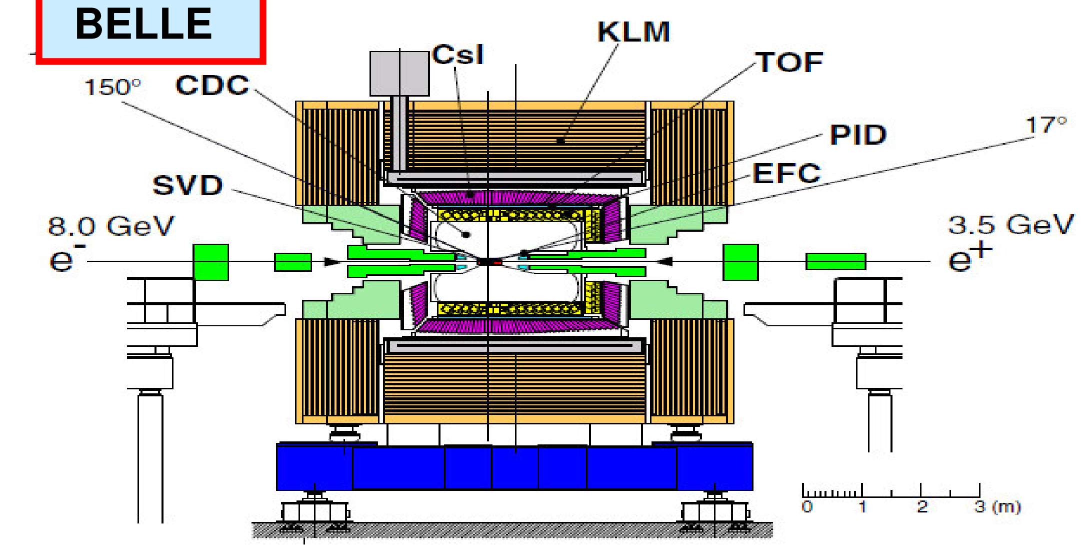
Detector for muons and neutral hadrons:

- Instrumented Flux Return
- 90% μ efficency

Particle Identification:

- Detector of Internally Reflected Cherenkov light (p>500 MeV/c)
- dE/dx in DCH (p<700 MeV/c)

BELLE



CDC:

- 93% of 4π
- $\Delta p/p = 0.35\%$

CsI Calorimeter (8736 crystals):

- $\Delta E/E = 1.8\%$ ($E\gamma > 3$GeV)

Muon Detector:

- μ efficency is > 90% (p>1GeV/c)

Particle Identification:

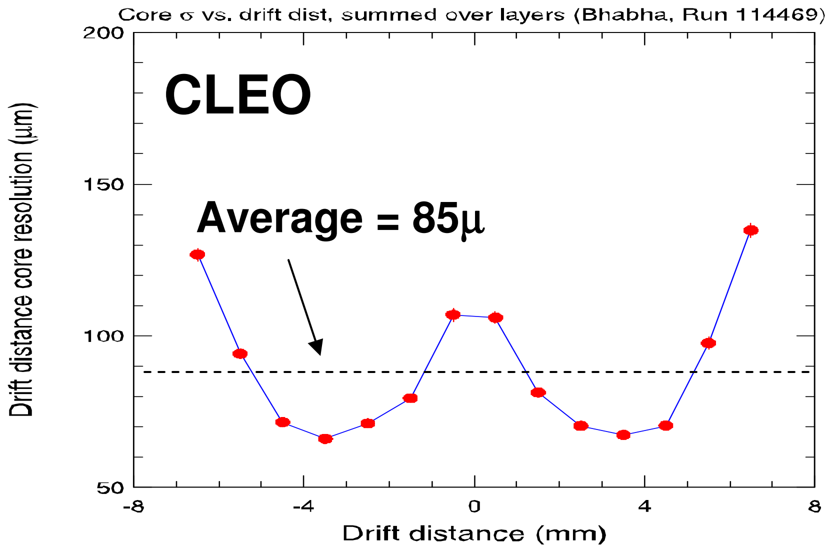
- TOF σT=95 ps
- Aerogel Cherenkov Counters
- dE/dx in CDC

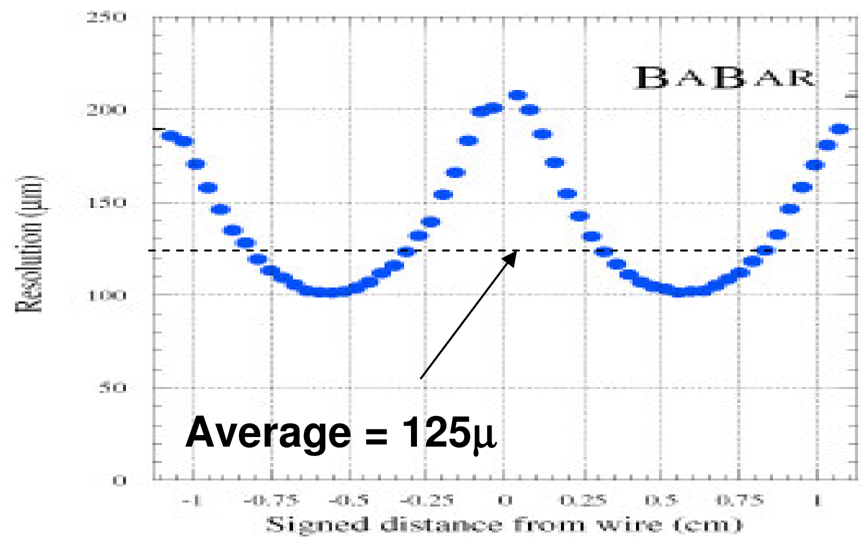
DCH Parameters of e^+e^- Collider Detectors

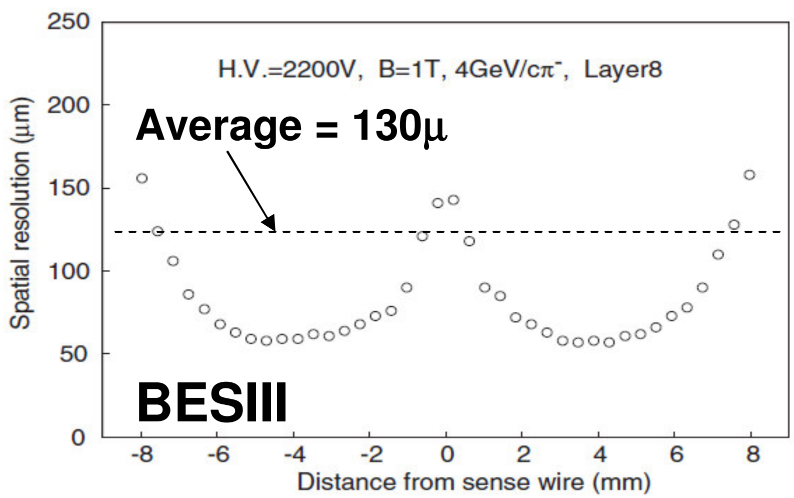
Detector	CLEO III	BaBar	BES III	BELLE
DCH Size (cm): R_Inner/R_Outer/Length	12.5 / 82 / (124.5 + 124.5)	24 / 81 / (101.5 + 174.9)	5.9 / 81 / (115.4 + 115.4)	15 / 115 / (77.0 + 160.0)
The Active Volume	$\lvert\cos\theta\rvert < 0.93$	$-0.92 < \cos\theta < 0.96$	$\lvert\cos\theta\rvert < 0.93$	$\lvert\cos\theta\rvert < 0.93$
Endplate Shape	Conical	Flat	Conical	Spherical
Number of layers	47	40	43	50
Number of Super-layers	8	10	11	18
DCH Cell# / Shape	9796 / Square	7104 / Hexagonal	6796 / Square	8400 / Square
Cell Size	1.4cm x 1.4cm	1.8cm x 1.2cm	1.2 cm x 1.2 cm 1.62cm x 1.62cm	1.7 cm x 1.6 cm
DCH Gas Mixture	He/Propane (60% / 40%)	He/Isobutane (80% / 20%)	He/Propane (60% / 40%)	He/Ethane (50% / 50%)
Sense Wires Voltage	1900 V	1930 V	2150 V	2300 V
Magnetic Field	1.5 T	1.5 T	1.0 T	1.5 T
DCH Hit Resolution	85μm	125μm	130μm	130μm
Drift Time / Drift Dist.	~300ns / 7mm	~500ns / 9mm	~350ns / 8mm	~350ns / 8mm
$\sigma p/p$	0.32%	0.48%	0.50%	0.35%
dE/dx Resolution	5.7%	7.5%	6.0%	6.9%

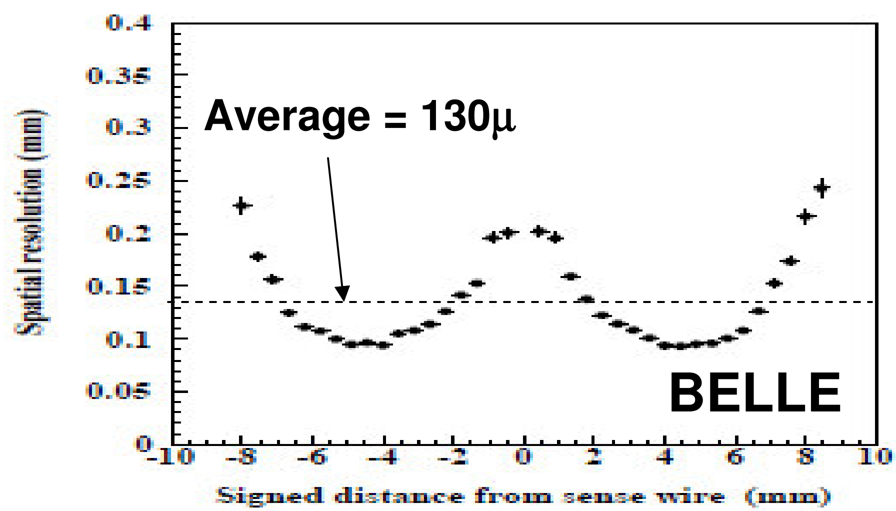
Comparison of the Spatial Resolutions for Different Detectors

The spatial resolutions as a function of the drift distance, separately for the left and the right side of the sense wire. The data is averaged over all cells in a layer.



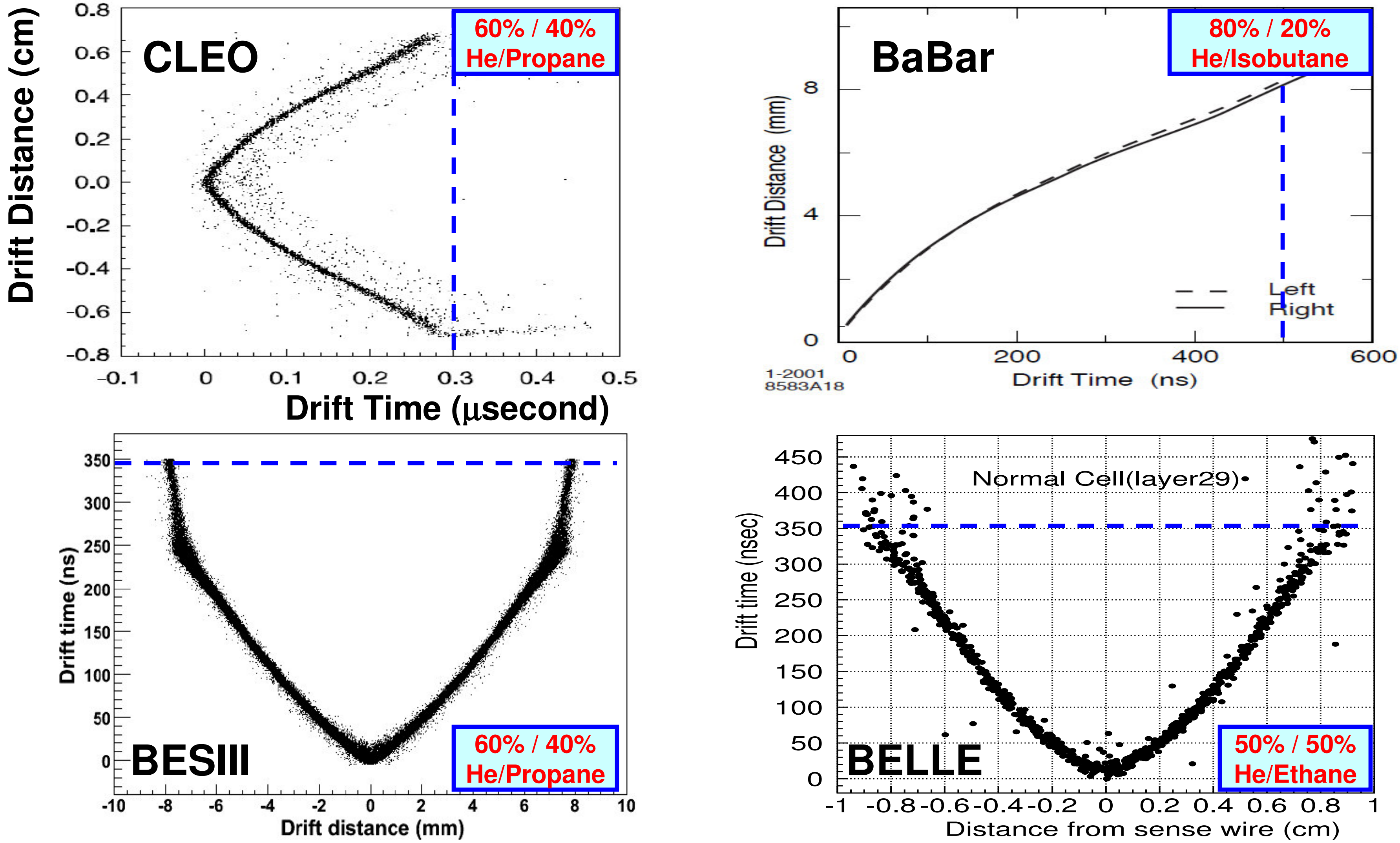






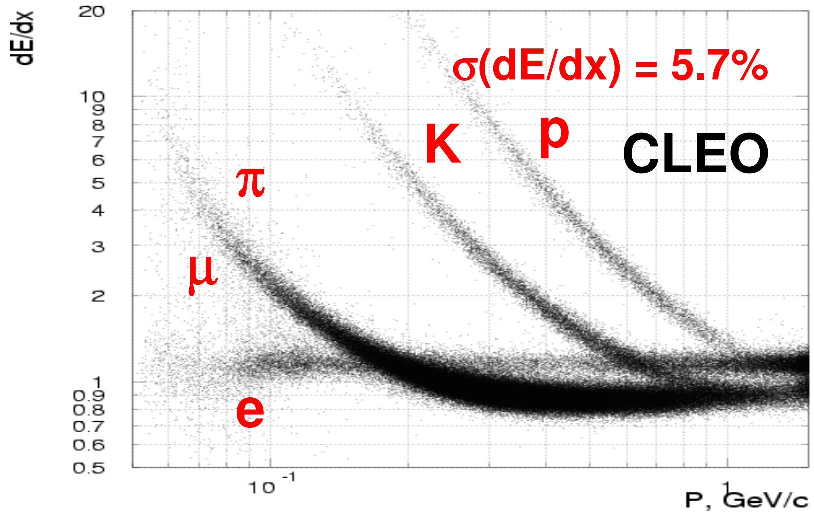
Comparison of Time-to-Distance Relations for Different Detectors

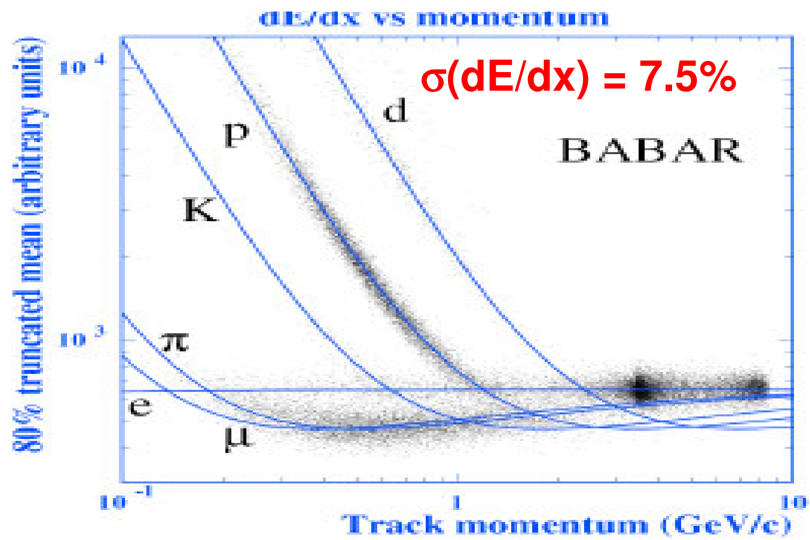
The drift distance is estimated by computing the distance of closest approach between the track and the wire.

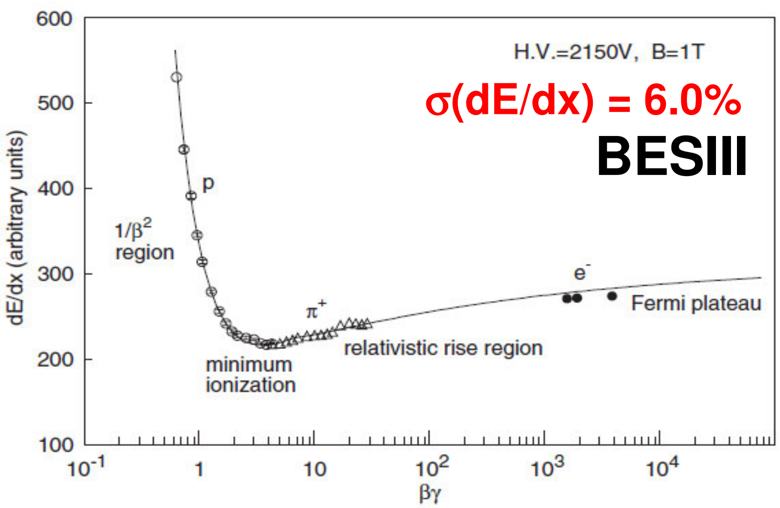


dE/dx for particles traversing the DCH for Different Detectors

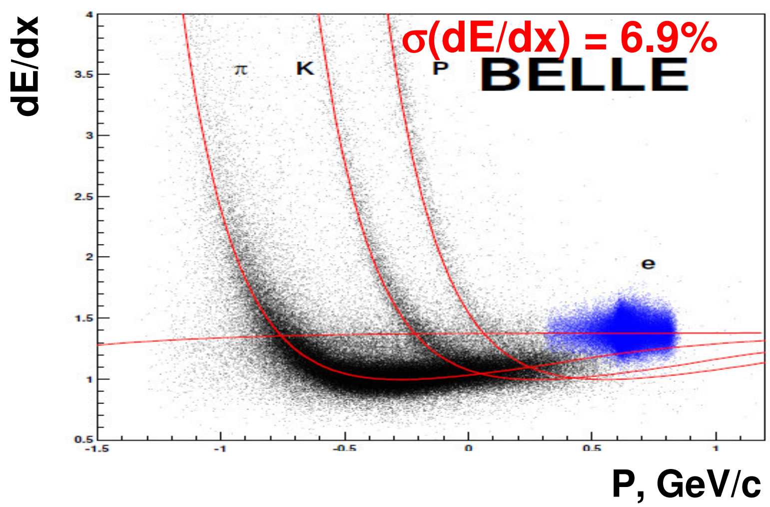
The specific energy loss, dE/dx, for charged particles traversing the DCH as a function of track momenta.







. Measured dE/dx vs. βγ.



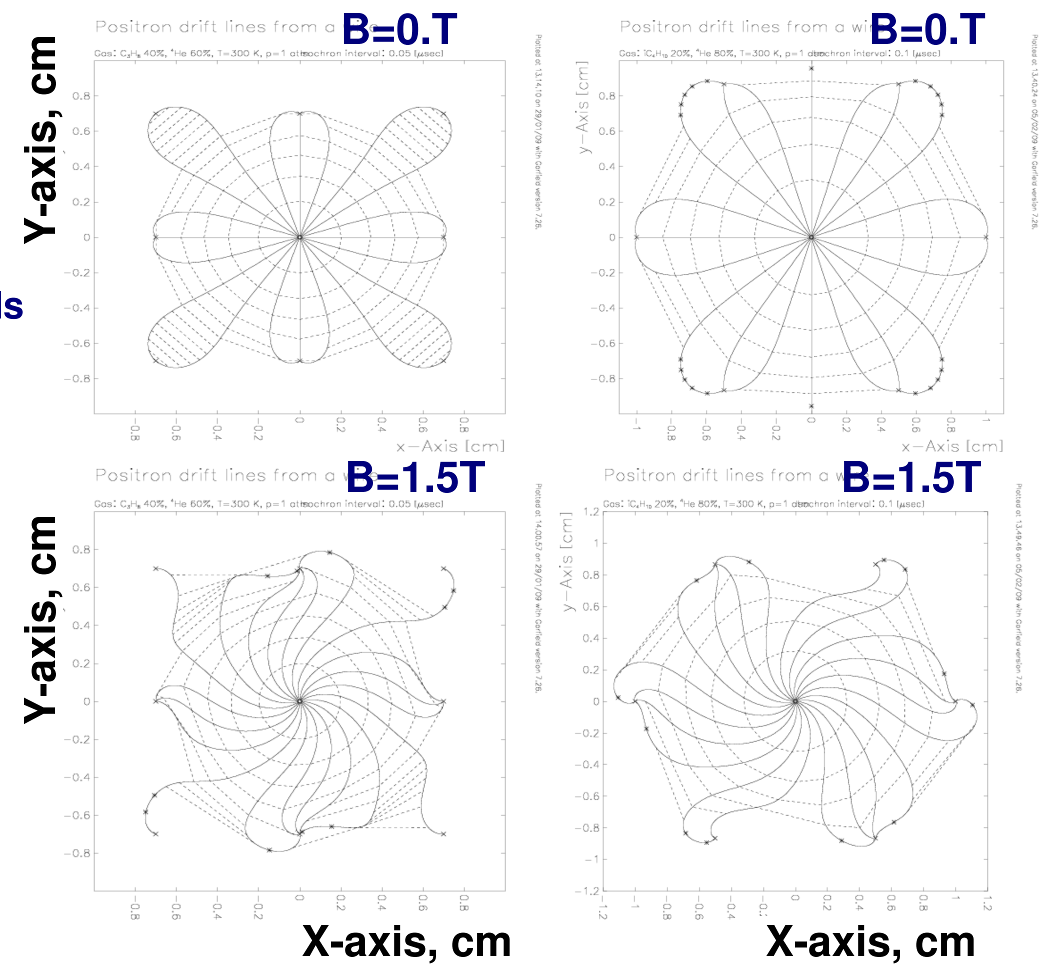
We studied the drift time dependence on:

- Gas composition
- Temperature & pressure variations
- Magnetic field

Garfield Input:

- Geometry of quadratic / hexagonal cells
- Voltage/E-field (1930V)
- Magnetic field (1.5T)
- Different gas compositions:
  - He / Propane
  - He / Isobutane
  - He / Ethane
  - Ar / Ethane
  - Ar / Ethane / CO_2
  - Ar / Methane / CO_2
- Gas Pressure
- Gas Temperature

Quadratic and Hexagonal Cells in Garfield



With the1.5T magnetic field the drift lines have a curvature.

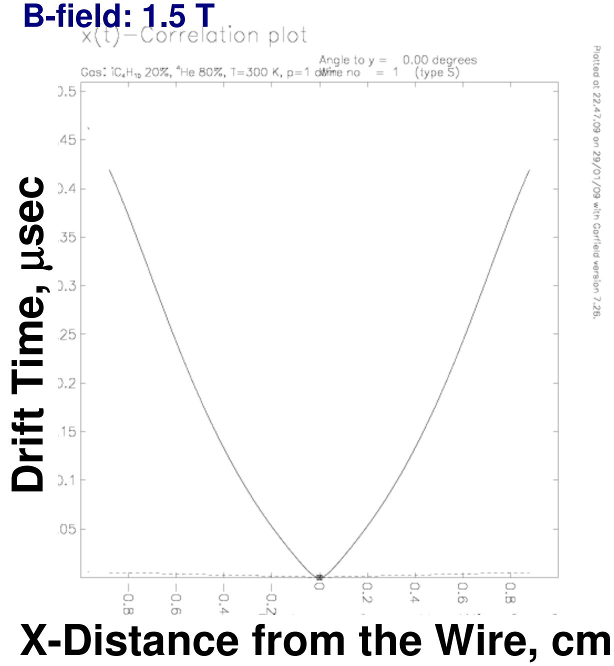
Garfield Output

Garfield Output: Distance-to-Time correlation, Lorentz angle, Drift velocity, Ionization loss (dE/dx) distributions, etc.

X(t) Correlation

The goal is to minimize drift time.

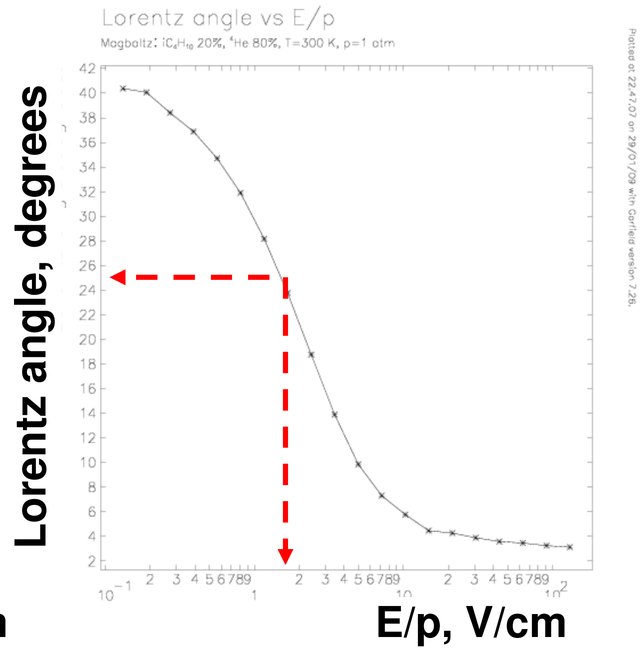
Gas: He/Isobutane (80% / 20%)
Pressure: 1atm
Temperature: 300º K
E-field: 1930V
B-field: 1.5 T



Lorentz Angle

The goal is to minimize Lorentz angle for straighter path.

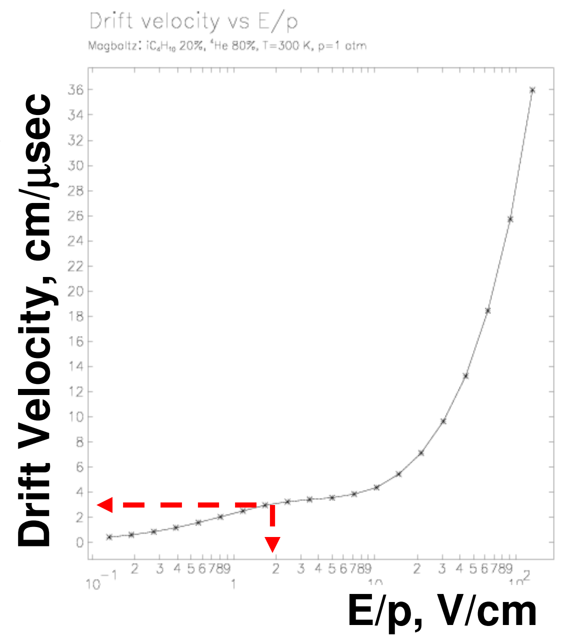
If Lorentz angle (↑)
drift path curvature also (↑)
➡ Problems with dE/dx calibration.



Drift Velocity

The goal is to maximize drift velocity.

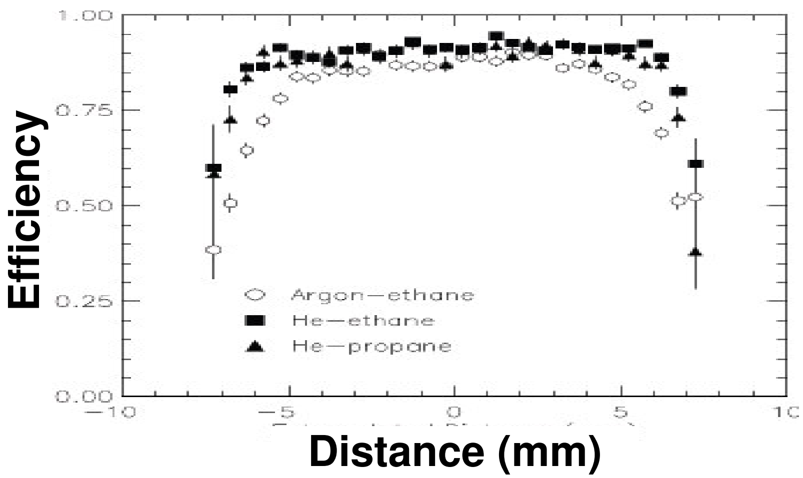
Greater drift velocity
➡ straighter path
➡ less dead time.

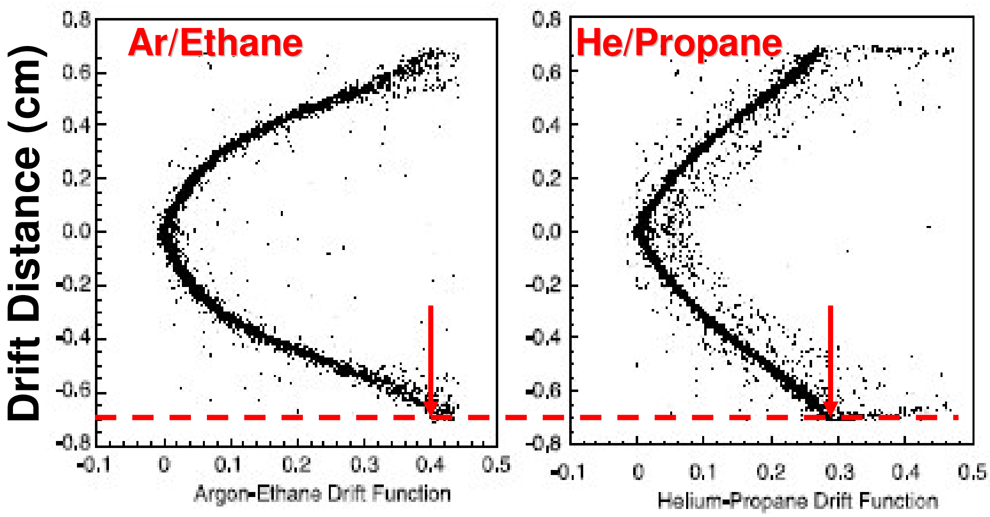


CLEO Gas Mixtures

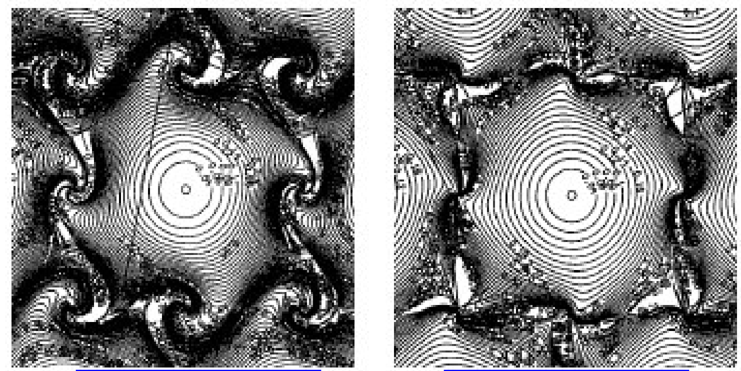
CLEOII - Ar/Ethane (50% / 50%)
CLEOIII - He / Propane (60% / 40%)

- **He / Propane Improves hit efficiencies.**





- **The peculiar distortions are caused by magnetic field.**
- **The lines shown are isochrones, which are lines of equal drift time.**
- **The Helium-Propane mixture has an Improved behavior.**
- **Isochrones near the cell boundary are almost square.**



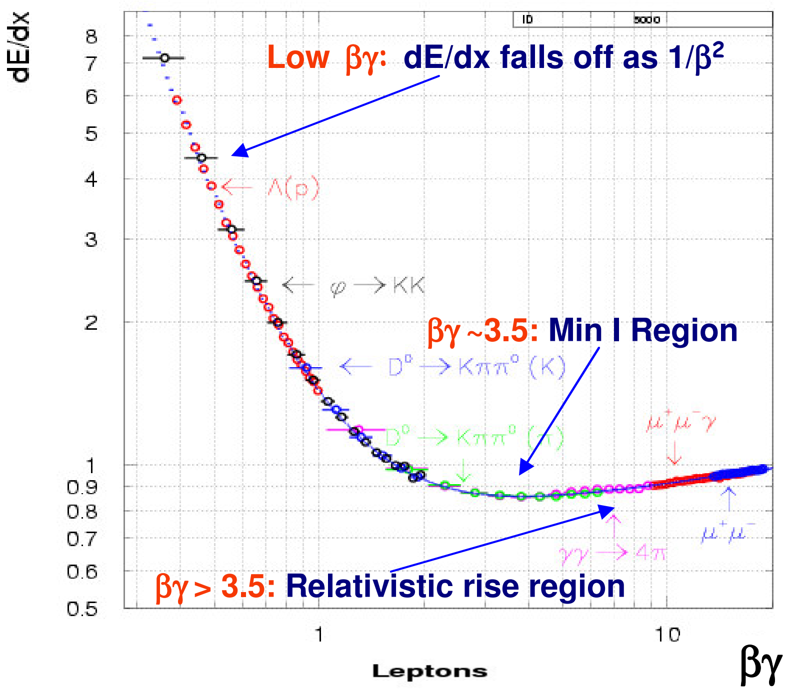
Ar/Ethane **He/Propane**

- **He / Propane has a smaller Lorentz angle and consistent drift velocity in 1.5 Tesla.**

He/Propane gas mixture improves dE/dx performance

dE/dx Performance at CLEO

dE/dx useful below RICH threshold and outside RICH solid angle.



For parameterization of dE/dx as a function of βγ we fit dE/dx vs βγ distribution in three βγ region: (0.-0.5), (0.5-7.5) and (7.5-50).

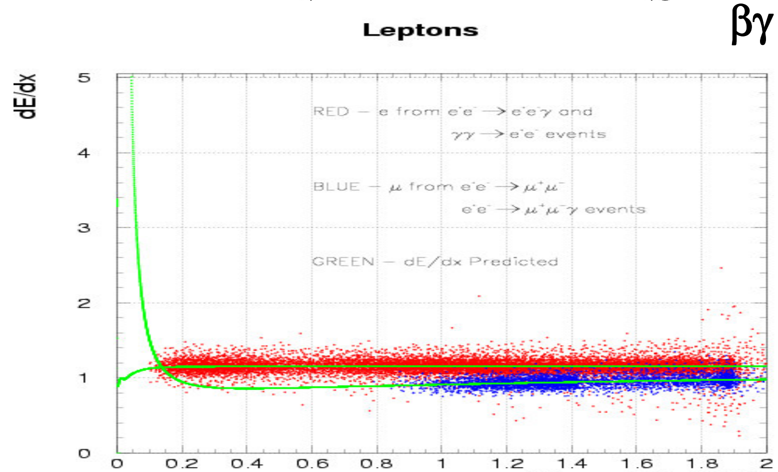
$dE/dx = A x (bg)^n + B_0 + B_1 x (bg) + B_2 x (bg)^2 + B_3 x (bg)^3$

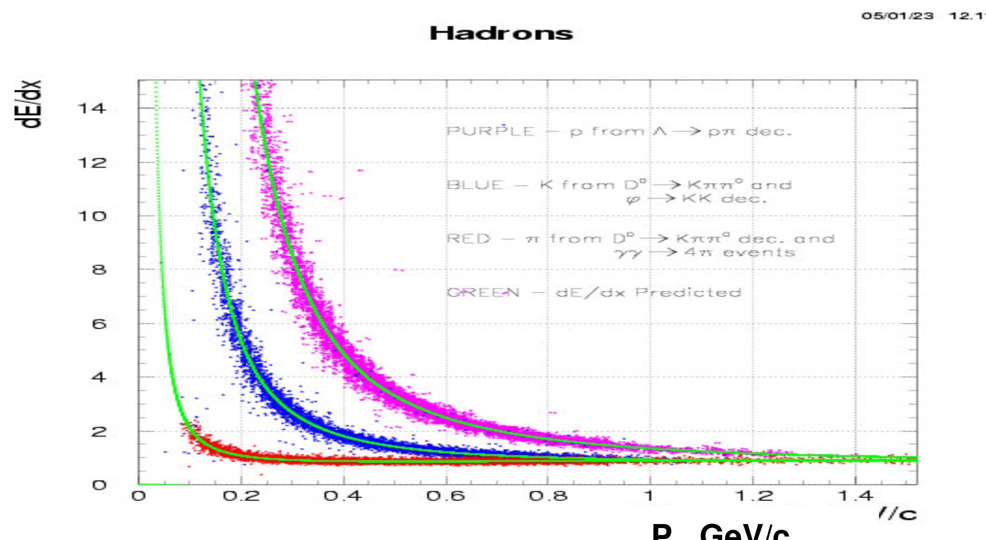
Function values should be equal at the transition.

In the region bg>50 exponential function was used: $dE/dx = C \times \exp(D \times \beta\gamma) + E$.

We use this parameterization to construct σ(dE/dx) variables.

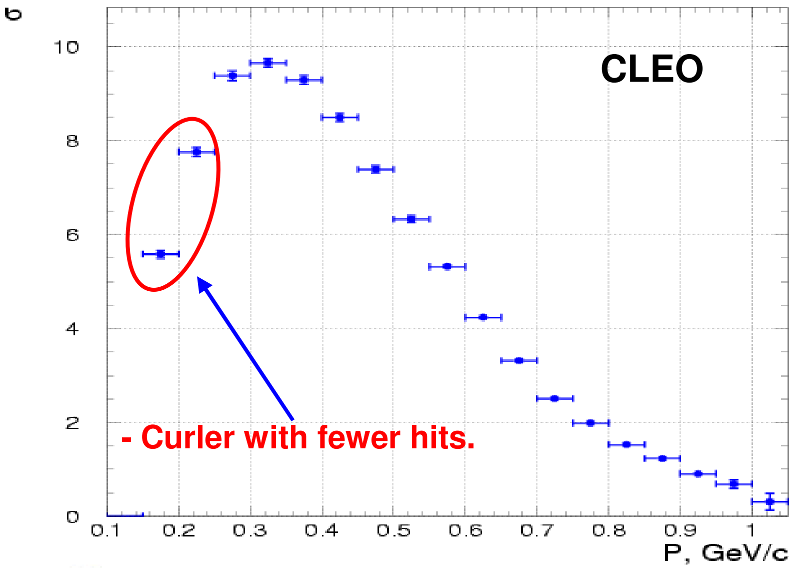
σ(dE/dx) is normalized deviation between observed $(dE/dx)_{meas}$ and predicted $(dE/dx)_{expected}$ values.



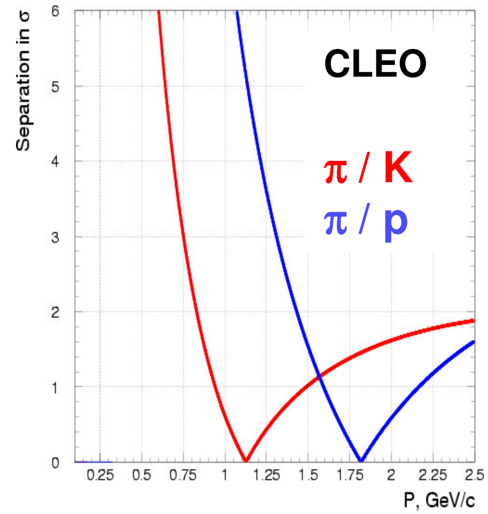


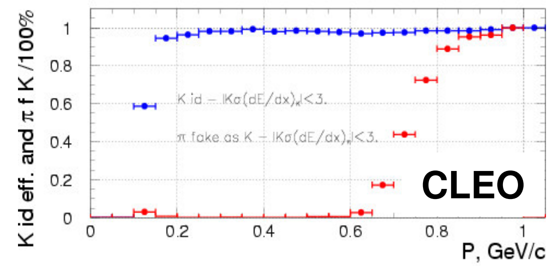
dE/dx Performance at CLEO, cntd.

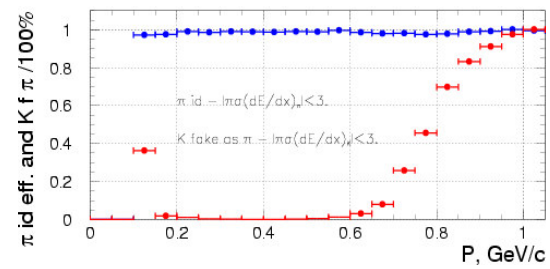
$$\sigma_{Sep.} = \frac{|M(dE/dx)_{\pi} - M(dE/dx)_{K}|}{(\sigma(dE/dx)_{\pi} + \sigma(dE/dx)_{K})/2}$$

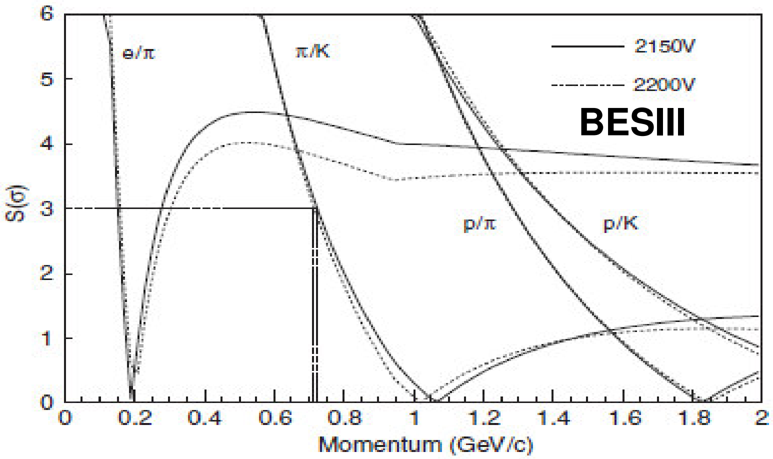


PID Efficiencies with dE/dx alone

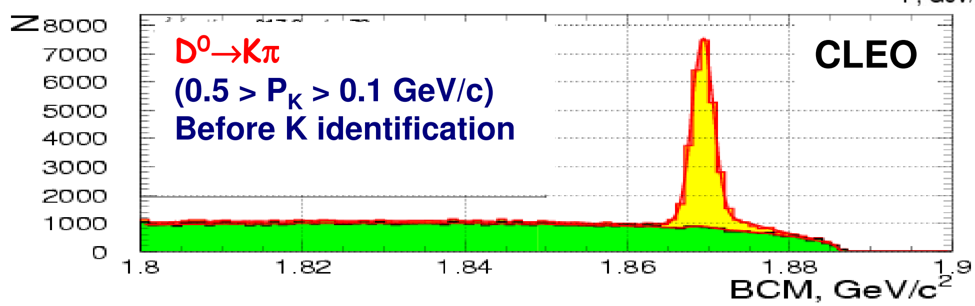


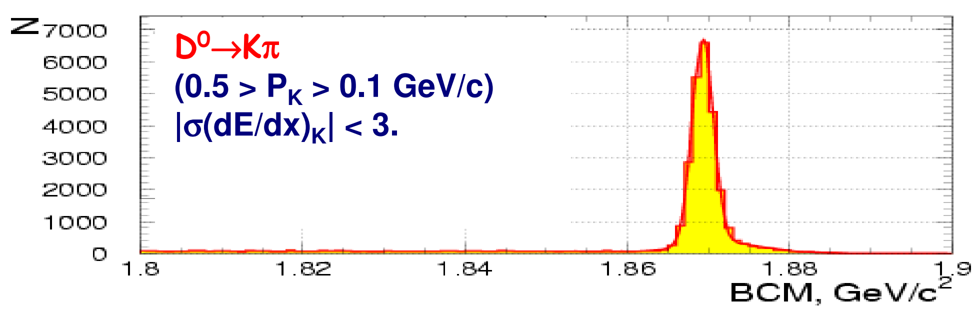






The separation power as a function of the momentum.





He / Isobutane (80% / 20%)

Motivation:

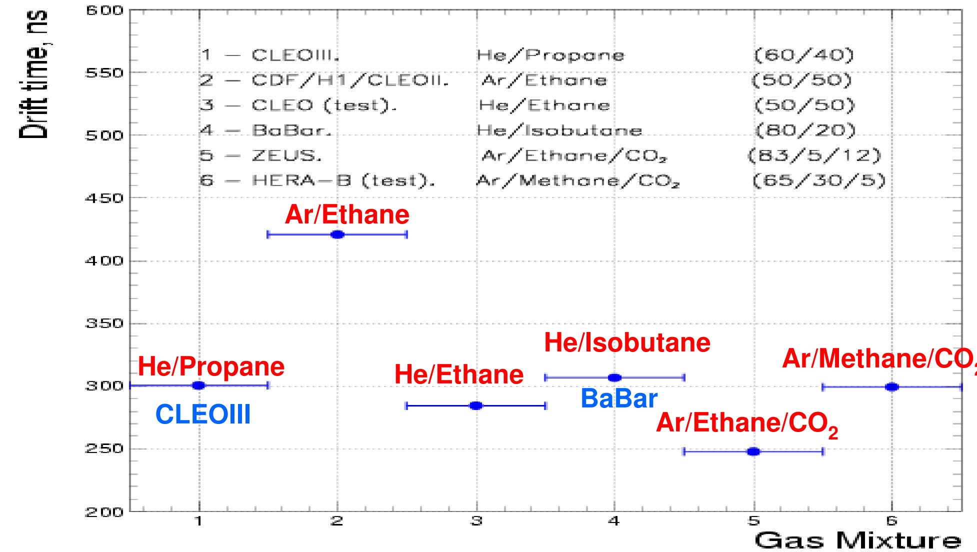
- This mixture has a radiation length that is 5x larger than Ar based gases.
- Isobutane absorbs photons, prevents photoelectric electrons.
- Keeps ionization local to particles trajectory.
- The smaller Lorentz angle results in a rather uniform time-distance relationship and improved spatial resolution.

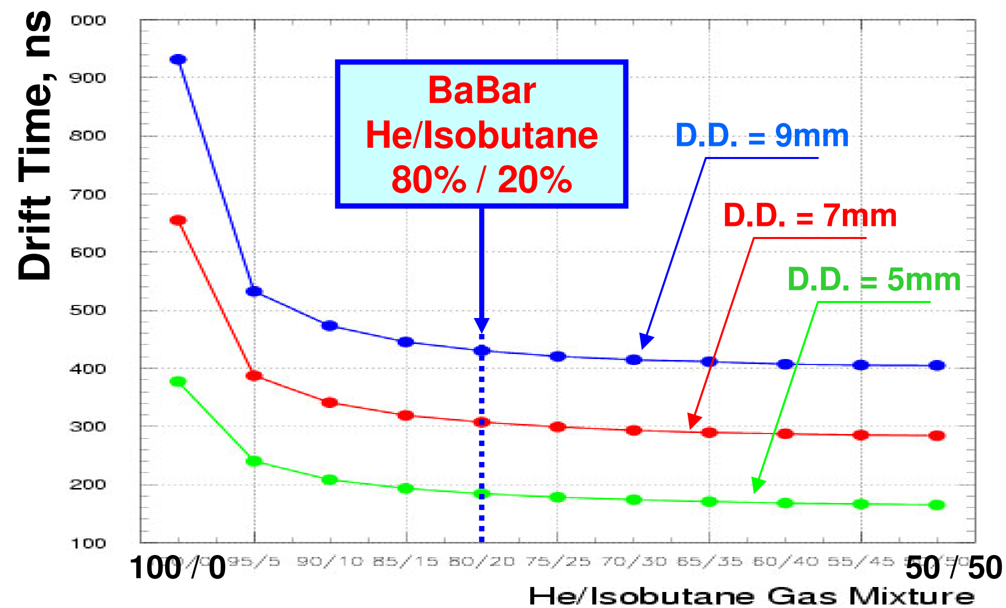
We varied He/Isobutane gas mixture to found better drift time and Lorentz angle.

- He / Isobutane (75%/25%) has slightly better drift time but (80% /20%) has a smaller Lorentz angle.

He / Isobutane (80% / 20%) mixture is a good compromise for a small drift time and Lorentz angle.

Small Hex Cell (D.D.=7mm)





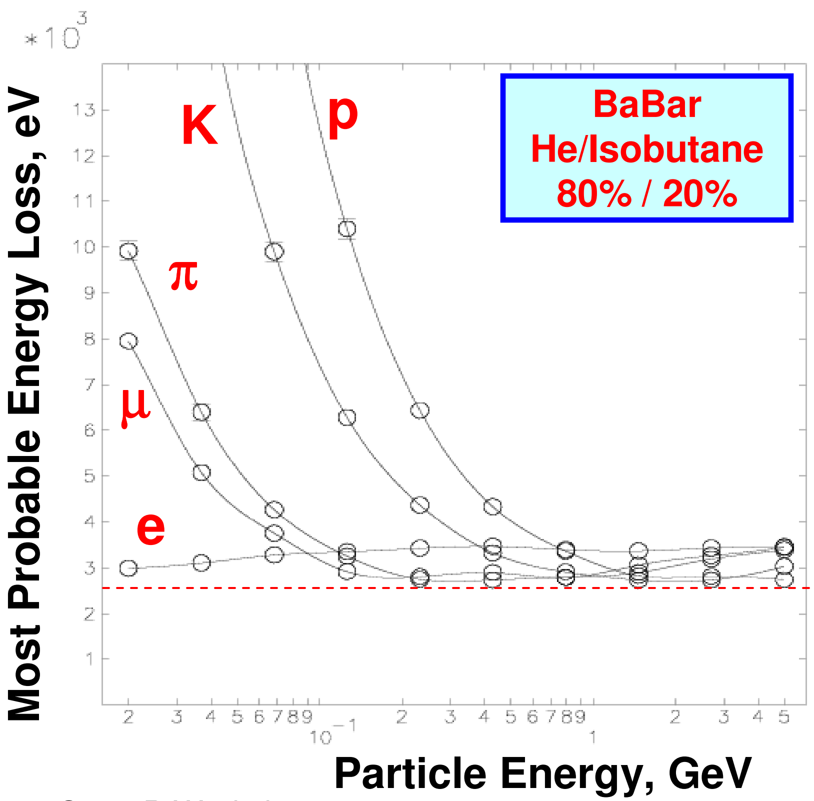
dE/dx for He/Isobutane & He/Propane Gas Mixtures

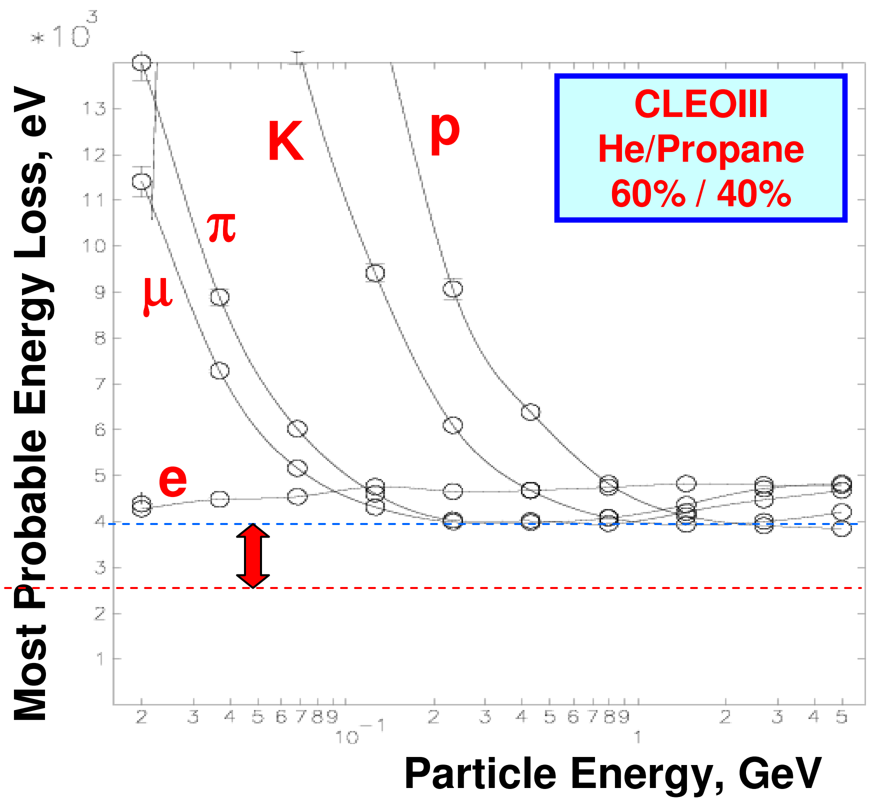
The energy lost by a particle traversing a gas depends on: gas mixture, gas pressure, temperature, particle energy, mass, charge etc.

The goal is to maximize energy loss for a stronger pulse and greater resolution.

Using the Heed program we compute the energy losses in He/Isobutane and He/Propane gas mixtures for various particles, as a function of the energy of the incoming particles.

The Heed program predicts more energy loss in He/Propane gas mixture than in He/Isobutane.





Magnetic Field Effect

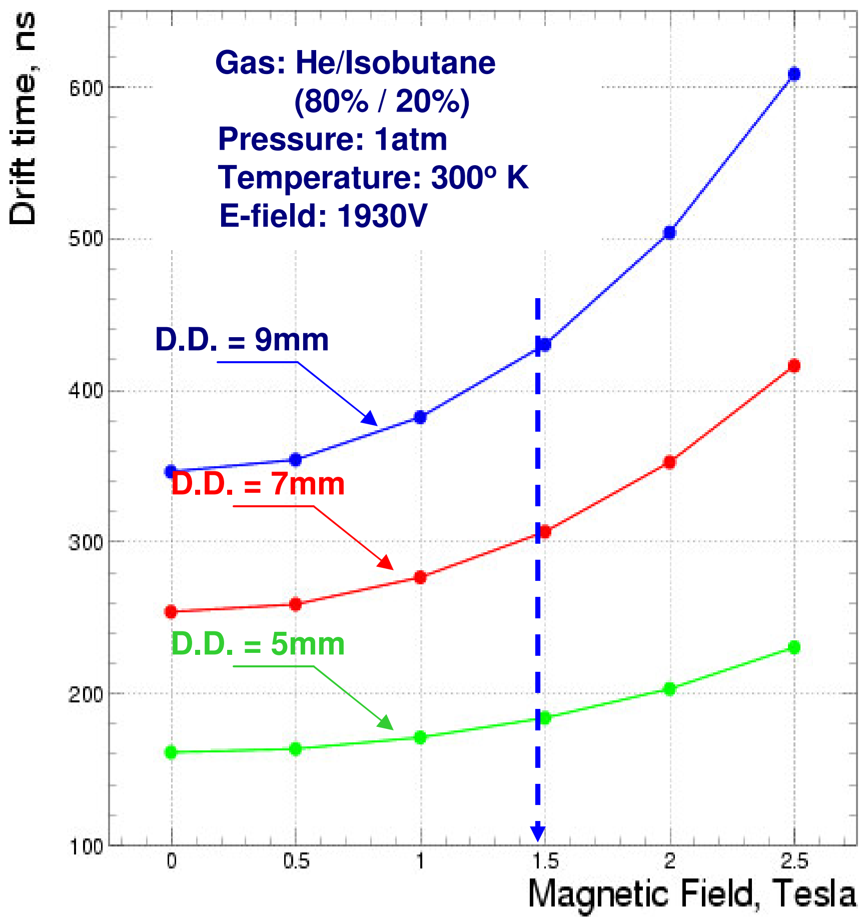
Simulation study have been performed investigating the drift time in He/Isobutane gas mixture for magnetic field varying from 0 to 2.5 Tesla.

Magnetic Field variation by
-0.5 Tesla / +0.5 Tesla from the nominal value (1.5 Tesla) changed drift time by:

-11.0% / +17.0% for D.D. = 9 mm,

-9.8% / +15.0% for D.D. = 7 mm,

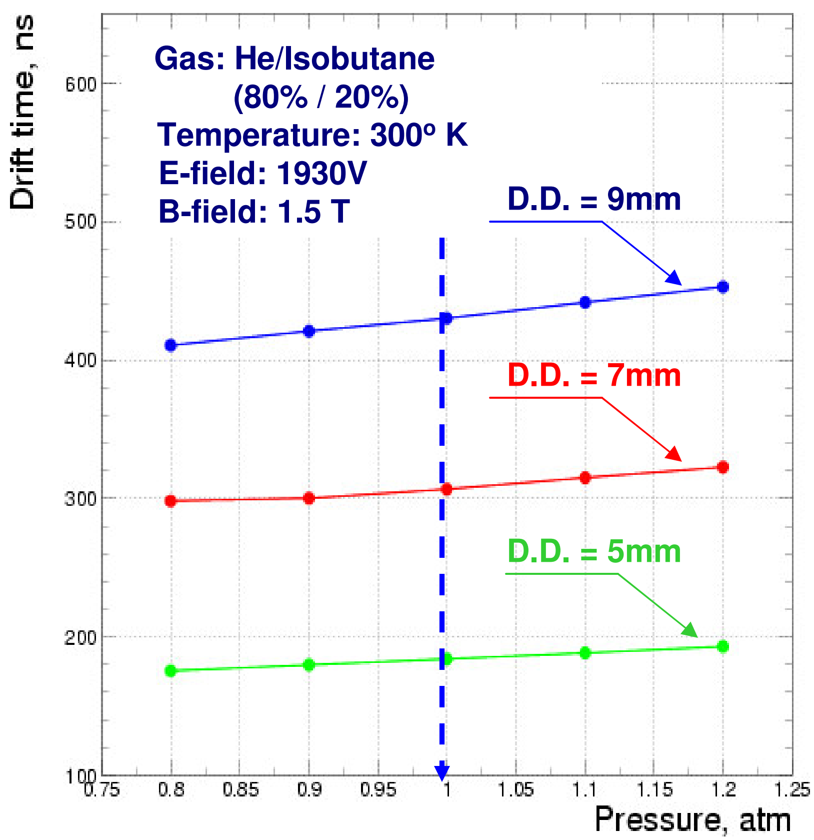
-7.0% / +10.5% for D.D. = 5 mm

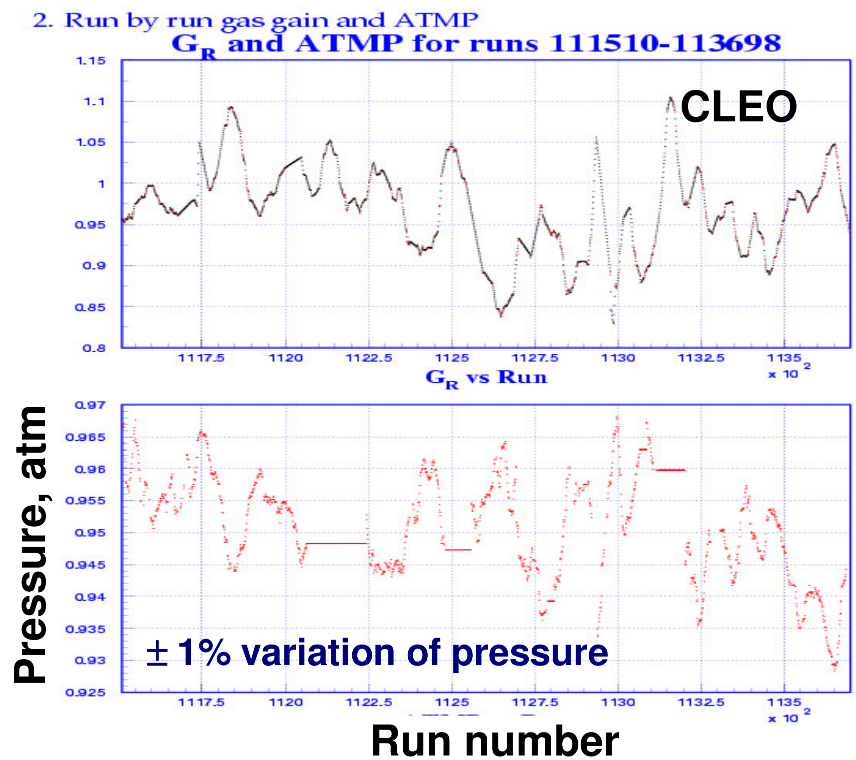


Pressure Effect

Gas equation: P=(n/V)RT. Temperature (T)=constant.

If pressure (P) (↑) ➡ number of molecules per volume (n/V) (↑) ➡ the mean free path (↓) ➡ the drift time (↑).



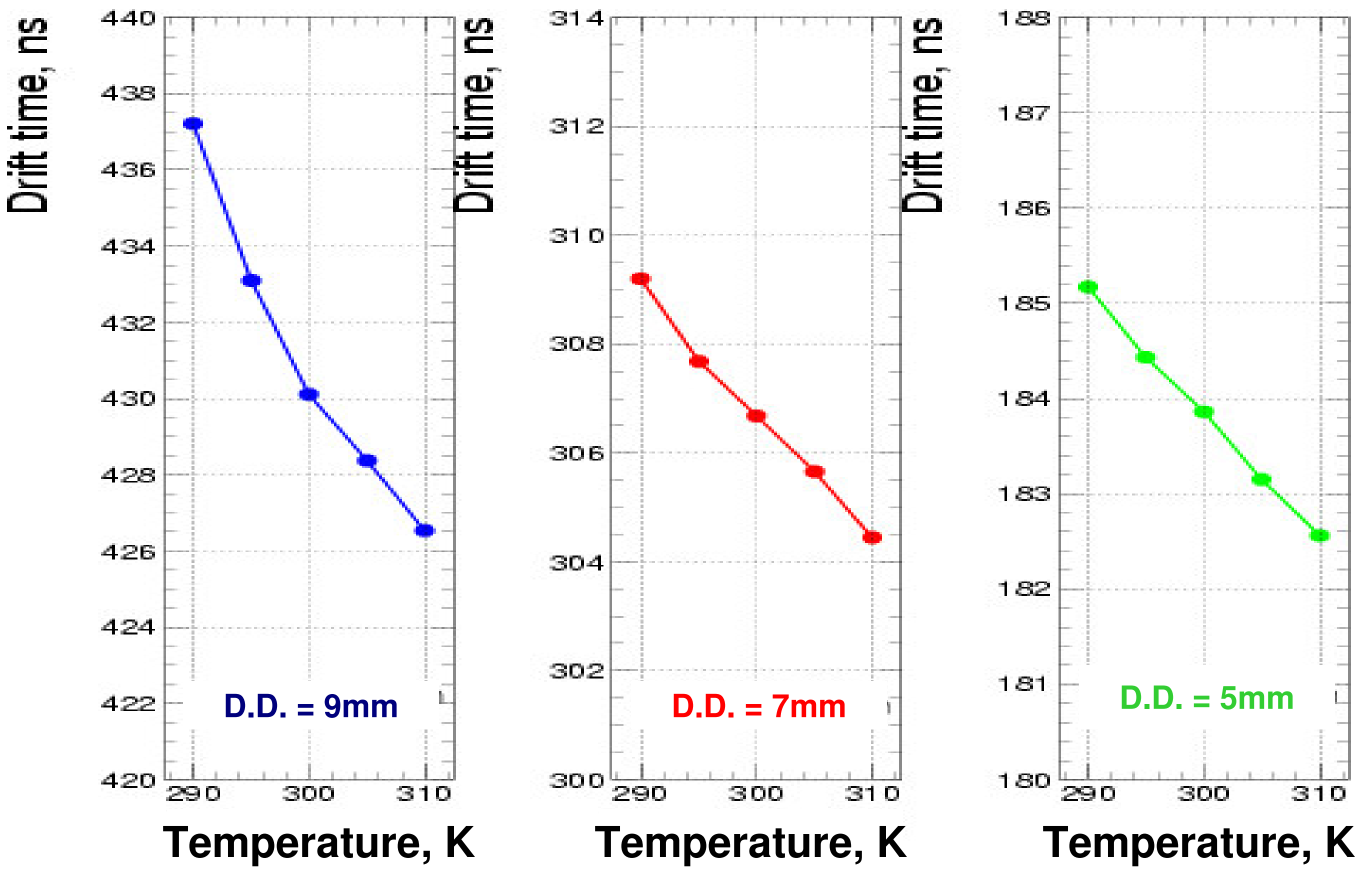


± 1% pressure variation = ± 0.2% of Drift Time variation in He/Isobutane gas mixture.

Temperature Effect

Gas equation: P=(n/V)RT. Pressure (P)=constant.

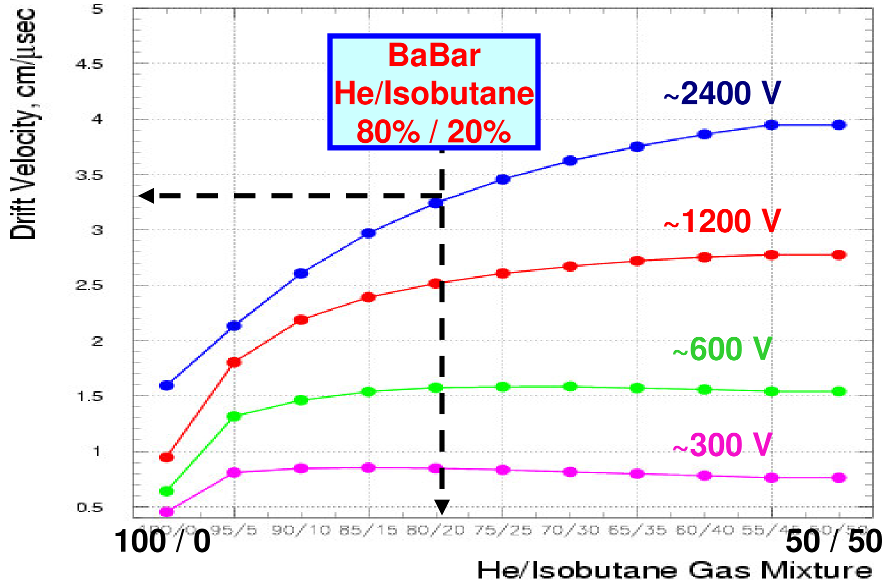
If temperature (T) (↑) ➡ number of molecules per volume (n/V) (↓) ➡ the mean free path (↑) ➡ the drift time (↓).

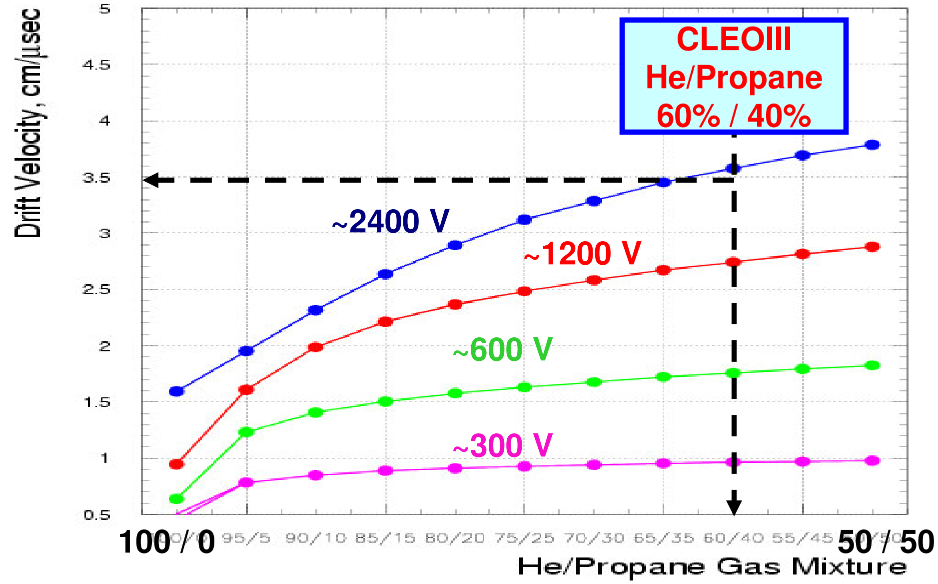


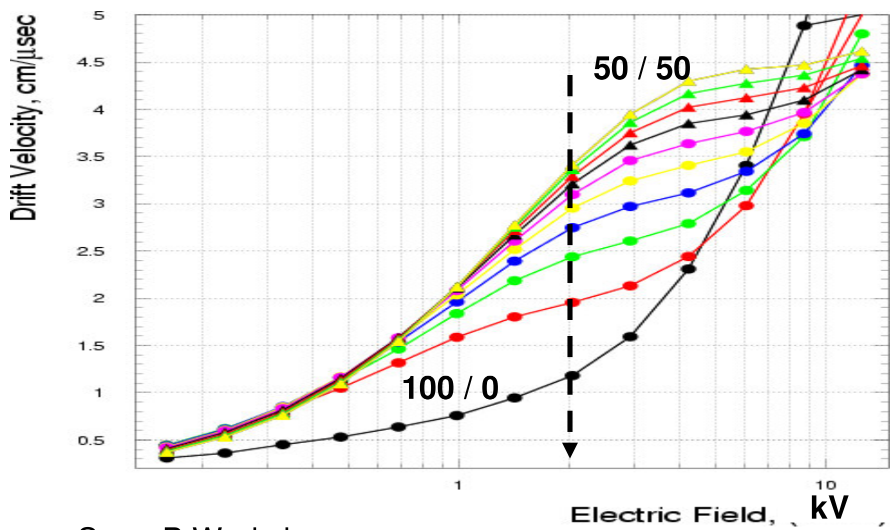
Gas: He/Isobutane (80% / 20%)
Pressure: 1atm
E-field: 1930V
B-field: 1.5 T

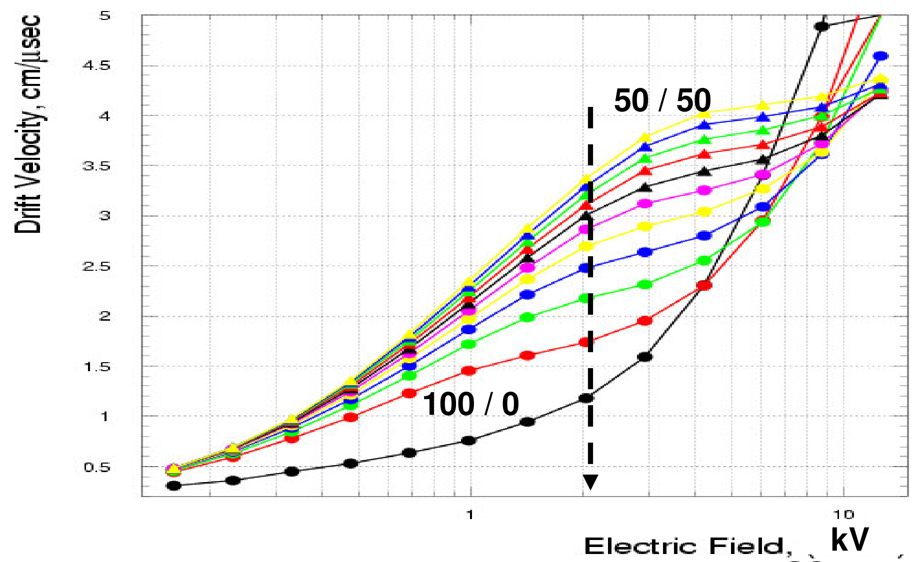
Drift Velocity Dependence on the Gas Composition & E-Field

Drift Velocity (He/Isobutane, 80%/20%) and Drift Velocity (He/Propane, 60%/40%) are consistent.



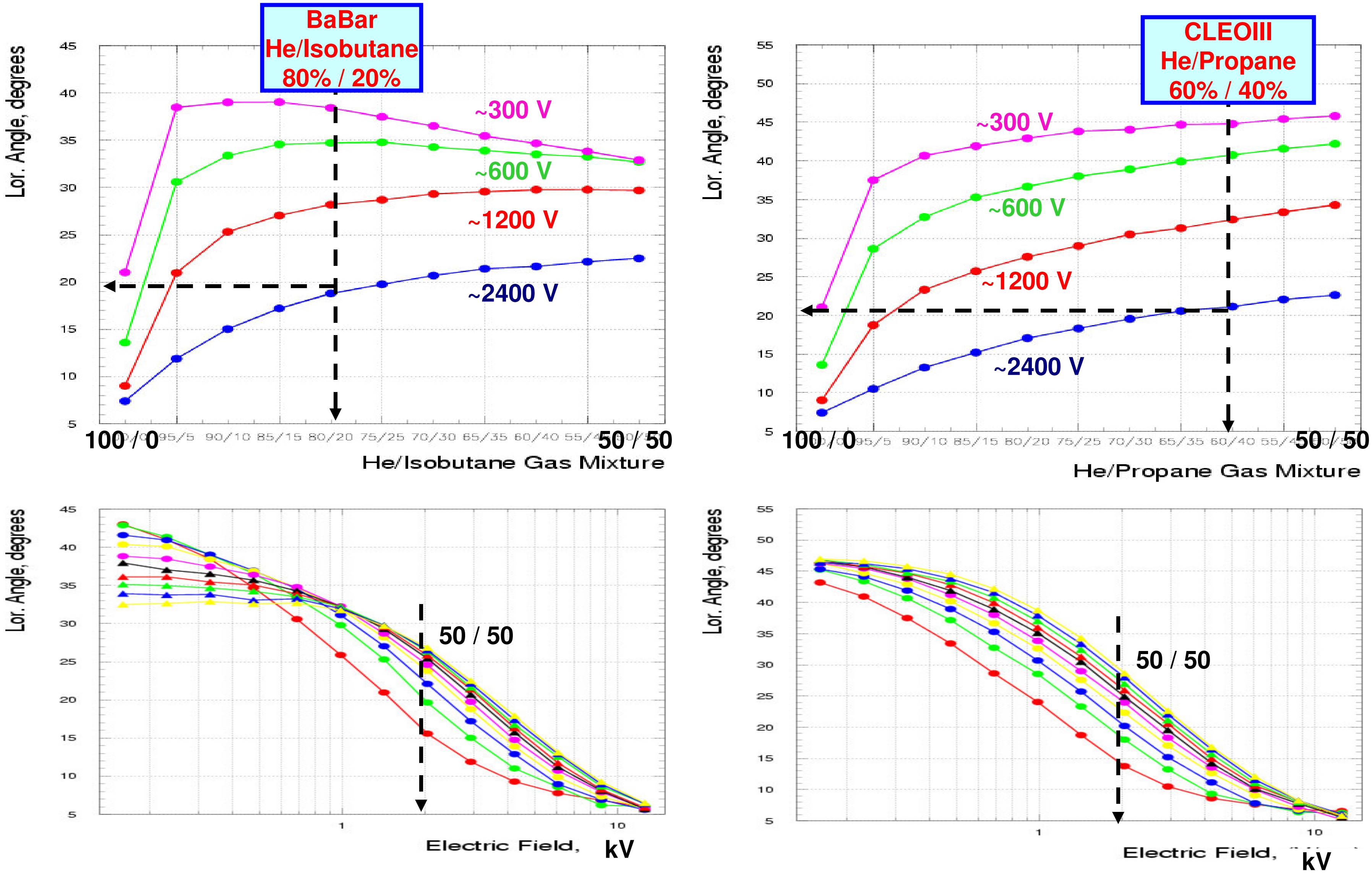






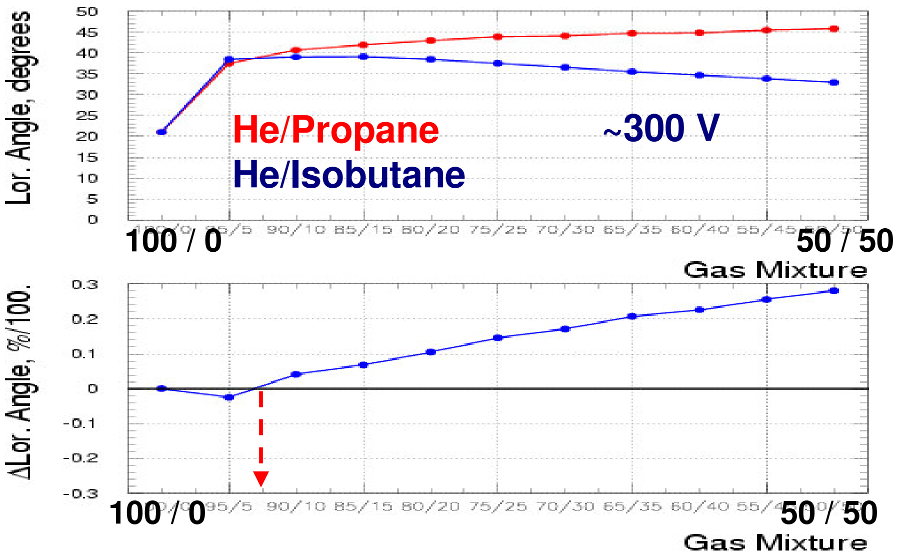
Lorentz Angle Dependence on the Gas Composition & E-Field

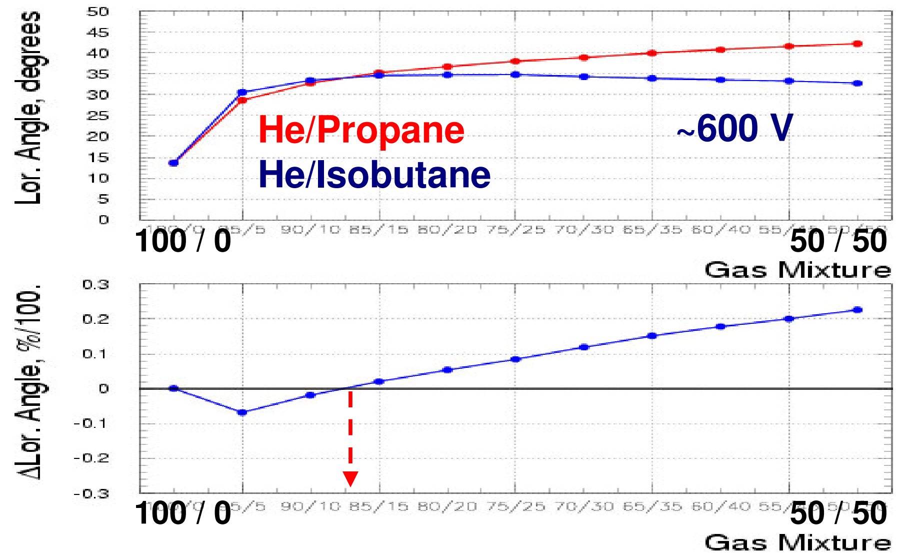
Lorentz Angle (He/Isobutane, 80%/20%) and Lorentz Angle (He/Propane, 60%/40%) are consistent.

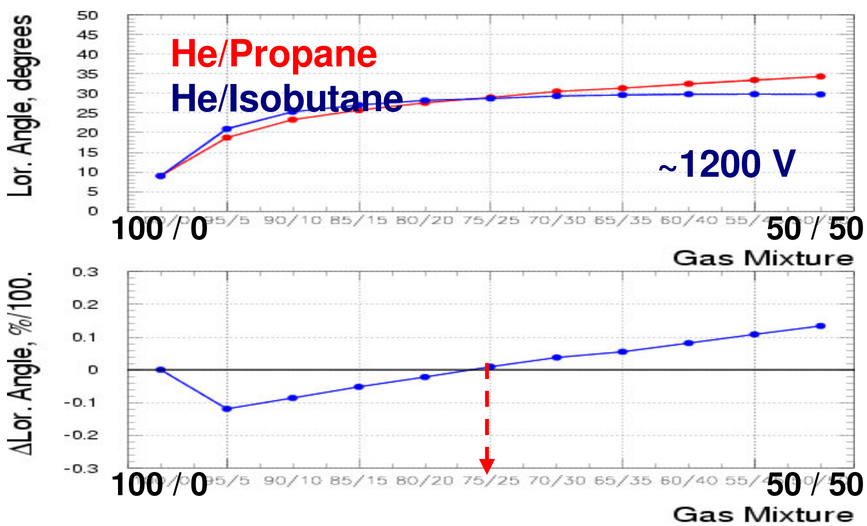


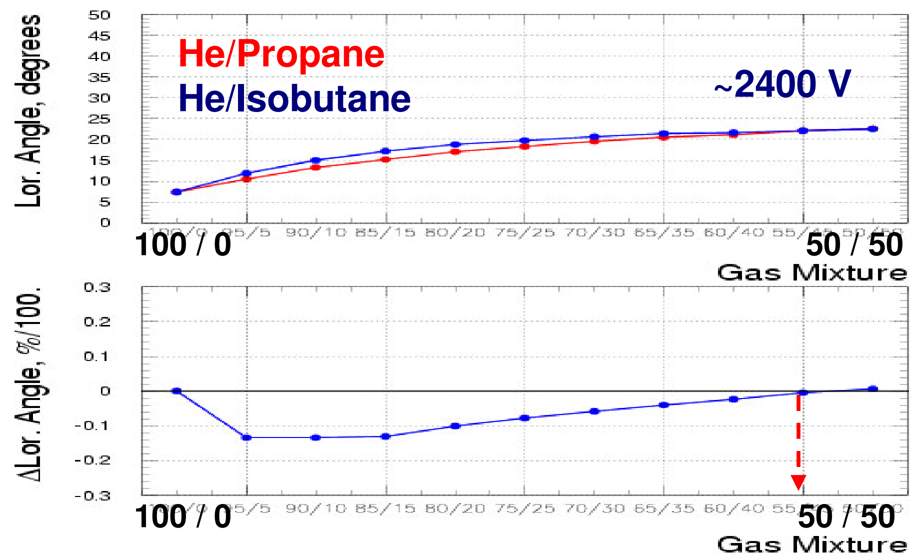
He/Propane & He/Isobutane Comparison

Same Lorentz Angle can be obtained for He/Isobutane and He/Propane gas mixtures at 300V: 92% He & 8% C_4H_{10} or C_3H_8 / 600V: 87% He & 13% C_4H_{10} or C_3H_8 / 1200V: 75% He & 25% C_4H_{10} or C_3H_8 / 2400V: 55% He & 45% C_4H_{10} or C_3H_8 …









Conclusion

- A simulator of gaseous detectors Garfield was used to investigate the characteristics of different gas mixtures that could improve a drift chamber operation.

- We studied the drift time dependence on: Gas composition, Temperature & pressure variations, Magnetic field.

- Using the program Heed we compute the energy losses of various particles in different gas mixtures as a function of the energy of the incoming particles.

- Simulations confirm that dE/dx resolution with He / Propane (60% / 40%) should be superior to He / Isobutane (80% / 20%).

- We do not yet understand the difference in momentum resolution
  - difficult to attribute to the choice of gas.
  - other design differences include
    - size and geometry of drift cell
    - structure of super layers
    - shape of endplates
    - support tube

- The optimal design of the SuperB DCH depends upon understanding the impact of these design choices on the momentum resolution.